NORTH CAROLINA
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
GEORGE R. ROSS, DIRECTOR

DIVISION OF MINERAL RESOURCES
JASPER L. STUCKEY, STATE GEOLOGIST

BULLETIN NUMBER 65

Geology and Structure of Part of the Spruce Pine District, North Carolina

A PROGRESS REPORT

BY

JOHN M. PARKER, III
GEOLOGICAL SURVEY, U. S. DEPARTMENT OF THE INTERIOR

PRESENTING THE RESULTS OF A COOPERATIVE UNDERTAKING BETWEEN THE U. S. GEOLOGICAL SURVEY AND THE NORTH CAROLINA DEPARTMENT OF CONSERVATION AND DEVELOPMENT.

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MEMBERS OF THE BOARD OF CONSERVATION AND DEVELOPMENT

LETTER OF TRANSMITTAL

Raleigh, North Carolina
October 22, 1952

To His Excellency, HONORABLE W. KERR SCOTT
Governor of North Carolina

SIR:

I have the honor to submit herewith manuscript for publication as Bulletin 65, "Geology and Structure of Part of the Spruce Pine District, North Carolina." This Bulletin is another in the series being made possible by the cooperation of the U. S. Geological Survey.

This report covers a part of the most important pegmatite district in the United States. It is believed that the information contained herein will be of considerable value to those interested in pegmatites and pegmatite minerals.

Respectfully submitted,

GEORGE R. ROSS,
Director

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GEOLOGY AND STRUCTURE OF PART OF THE SPRUCE PINE DISTRICT, NORTH CAROLINA

A PROGRESS REPORT

By John M. Parker, III

ABSTRACT

General geologic mapping and detailed studies of many mica, feldspar, and kaolin deposits have been made by the U. S. Geological Survey since 1939 in the Spruce Pine pegmatite district, North Carolina. Much of this work has been in cooperation with The North Carolina Department of Conservation and Development. The area is near the western border of the state, in Avery, Mitchell, and Yancey Counties.

The district is underlain by crystalline metamorphic and igneous rocks that may be grouped as follows: (1) metamorphic rocks derived by regional dynamic metamorphism from interbedded sedimentary and perhaps volcanic rocks of pre-Cambrian or early Paleozoic age; (2) metamorphic and igneous rocks altered by hydrothermal solutions or by injection of magma; and (3) intrusive igneous rocks of early(?) and late Paleozoic age. The metamorphic group includes mica gneisses and mica schists, and dolomitic marble of sedimentary origin, and hornblende gneiss and schist that may have been derived from impure dolomite, from mafic volcanic rocks, or possibly from mafic sills. The altered rocks include feldspathic mica injection gneiss developed mainly from mica schist and gneiss impregnated with pegmatitic material, and chlorite amphibolite, chlorite-biotite schist, soapstone, talc schist, and asbestos rock formed largely by alteration of hornblendic rocks and, to a lesser extent, of dunite. The igneous group includes a few bodies of dunite and pyroxenite, probably of early or middle Paleozoic age, a great number of fine- to coarse-grained pegmatite bodies that range in size from stringers to stocklike masses, of Carboniferous age, a few aplite dikes apparently related closely to pegmatite, and a few diabasic basalt dikes, probably of Triassic age. Bedrock is generally mantled with residual soil and in many places is covered with unconsolidated surficial deposits that include terrace sediments, floodplain alluvium, and talus and landslide deposits.

The schists and gneisses are interlayered with one another in bands that range from a fraction of an inch to several hundred feet in thickness. The layers pinch out or thicken along their strike so that they interfinger complexly. Few isoclinal folds are recognized. Foliation (flow cleavage) is parallel to the layering almost everywhere. The general strike is northeast and the dip is southeast, but locally diverse attitudes are common. Drag folds commonly plunge south or southwest. Faults of small displacement are numerous; no large ones are surely known. Regular tectonic joints are confined almost entirely to hornblendic rocks. Large bodies of fine-grained pegmatite have deformed their walls slightly; they contain many inclusions.

The major mineral products of the area are feldspar, kaolin, scrap mica, and sheet mica. Other minor or potential mineral products include beryl, columbium-tantalum minerals, quartz, rare earth and uranium minerals, amphibole asbestos, building stone and crushed rock, chromite, garnet, kyanite, mica schist, olivine, and vermiculite.

INTRODUCTION

LOCATION OF DISTRICT

The Spruce Pine pegmatite district in North Carolina (fig. 1) is near the middle of the western boundary of the state, in Avery, Mitchell, and Yancey Counties. It lies just west of the Blue Ridge drainage divide in rugged mountain country of the upper reaches of the Toe River, a tributary of the Tennessee River system.

The district includes about 250 square miles; it extends about 25 miles in a northeasterly direction and is about 12 miles wide. The town of Spruce Pine, midway of the district near its southeast side, is the

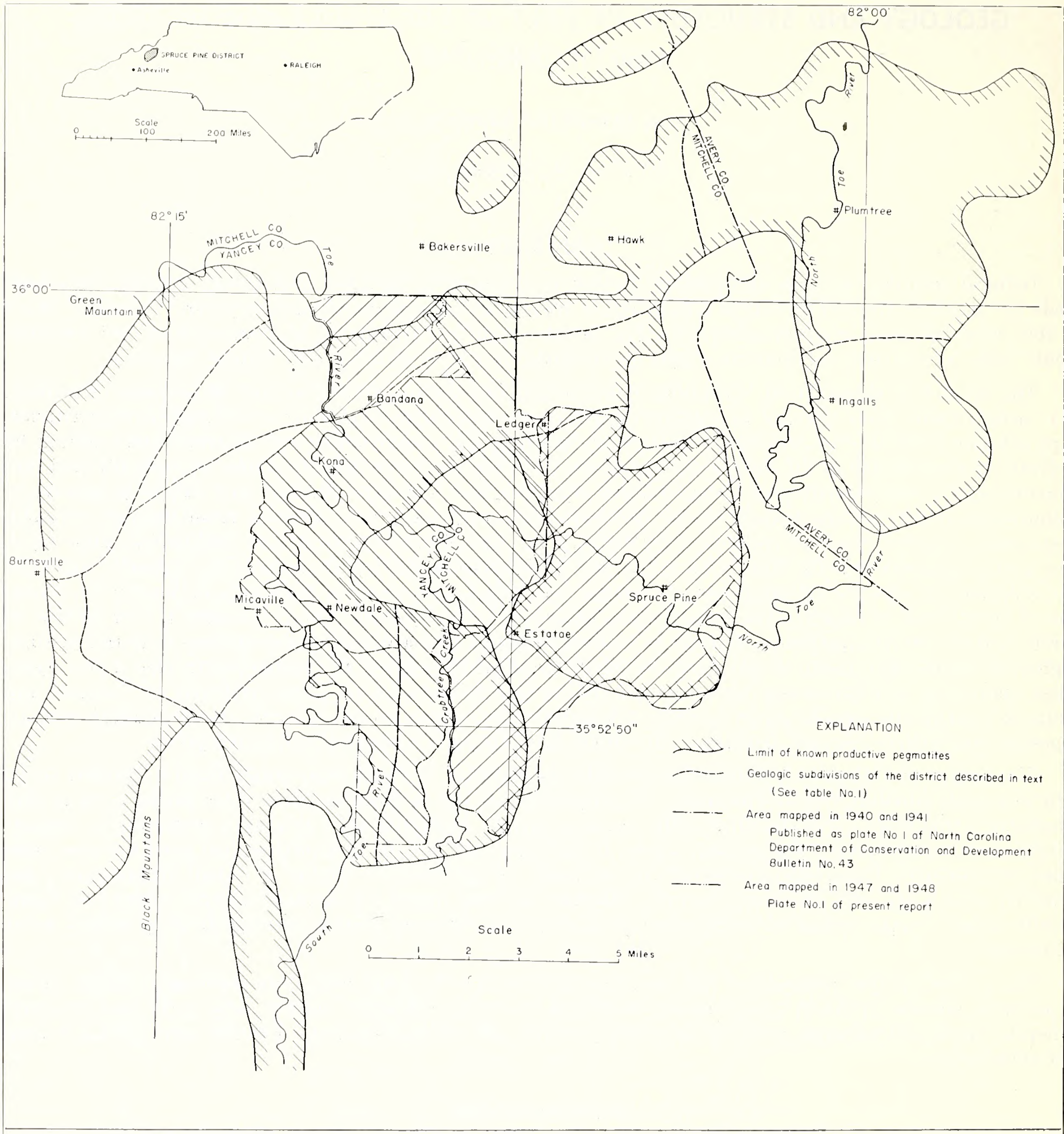

Figure 1 Index Map of the Spruce Pine District, North Carolina

commercial center. The Carolina, Clinchfield, and Ohio Railroad; U. S. Highway 19-E; and State Highway 26 cross the area.

The district is covered by parts of the following topographic maps of the U. S. Geological Survey: Mount Mitchell, Morganton, Roan Mountain, and Cranberry 30-minute quadrangles, and by the Bakersville, Carvers Gap, Newland, Burnsville, Micaville, Spruce Pine, Linville Falls, Black Brothers, Celo, and Woods Mountain 7½-minute quadrangles.

HISTORY

Mining of various nonmetallic minerals has been a major industry in the district for some 80 years. The district has, in fact, been the principal mining center in the Southeast for mica, feldspar, and residual white clay. Sheet mica has been mined since about 1868, and in the years since then the district is estimated to have yielded nearly half of the Nation's total production of this mineral. Since about 1893 scrap mica for grinding has been an important byproduct, and in later years a primary product. Feldspar was first shipped in 1911, and in most years since 1917 North Carolina has ranked first among the feldspar-producing states. The greater part of the state's production has been in the Spruce Pine district. White china clay has been produced since about 1904, and during the past 30 years the district has been almost the sole source of residual kaolin in eastern United States. In addition there has been a relatively small production of amphibole asbestos, beryl, columbium-tantalum minerals, kyanite, ground mica from schist, olivine, quartz, vermiculite, and, for local use, soapstone, various gneissic building stones, and crushed rock.

SUMMARY OF INVESTIGATIONS IN THE DISTRICT

Geologic investigations in the Spruce Pine district by the U. S. Geological Survey began in 1893 with the small-scale (1/125,000) mapping of the mountain areas by Arthur Keith (1903; 1905; 1907). In 1904-1906 and again in 1914 some of the mica and feldspar deposits were examined and mapped by D. B. Sterrett (1923) ; part of this work was supported by the North Carolina Geological and Economic Survey. Watts (1913) studied the feldspar and kaolin deposits about 1912 for the U. S. Bureau of Mines. The kaolin deposits were again investigated in 1918 by W. S. Bayley (1925), also in cooperation with the North Carolina Geological and Economic Survey.

Intensive investigations of the pegmatite deposits were begun in 1939 by the U. S. Geological Survey with the economic studies of Kesler and Olson (1942). General areal geologic mapping of the Spruce Pine district on a larger scale (1/24,000) was commenced in 1940 by J. M. Parker, III, and continued in 1941 by Parker, J. C. Olson, and J. J. Page. The U. S. Geological Survey's work in the district after July 1941 was in cooperation with the North Carolina Department of Conservation and Development. The results of this mapping and of some later work were published under Olson's authorship (1944) in a bulletin that included a colored geologic map on a scale of approximately 1/17,000 of two areas totalling about 37 square miles near Spruce Pine and near Bandana in Mitchell County. In 1942 the kaolin deposits were reexamined as possible sources of aluminum ore by J. M. Parker, III, (1946) and some additional mapping was done.

During World War II detailed examinations and large-scale maps (1/240 to 1/600) were made for several hundred mica deposits. This work was carried on at different times by a total of 19 geologists and assistants, under the local supervision of J. C. Olson from December 1942 to May 1944, and of J. M. Parker, III, from then until October 1945. Many of these mine maps are available on open file in the U. S. and State Geological Survey offices. All of this material on mica deposits in the Blue Ridge areas of southeastern United States is in preparation for publication by the Geological Survey (Jahns et al.)

General geologic mapping of parts of the Spruce Pine district on a scale of 1/12,000 was resumed by R. H. Jahns between November 1945 and February 1946, and was continued by J. M. Parker, III, in August-September 1947, and by a party of five under Parker's direction between June and September 1948. At the close of the 1948 field season a total of about 72 square miles (fig. 1) had been mapped; of this about 37 square miles has been published (Olson, 1944, pl. 1). Within the 31 square miles mapped during 1948 some 450 pegmatites were examined; of these about 280 seemed to have economic value and their inferred resources were estimated. Thin sections of about 40 rocks were examined microscopically by D. A. Brobst in the University of Minnesota petrographic laboratories during the winter 1948-1949. His descriptions are incorporated in this report. Studies of decomposed rocks were made by thermal and spectographic methods at Columbia University by J. L. Kulp during the same period; these results will be published separately.

In addition to the U. S. Geological Survey's work, several other studies of economic minerals have been made in the district. The results of these recent significant investigations are given in the publications listed among the references at the end of this report.

SCOPE OF PRESENT REPORT

The present report is a summary of current knowledge of the general geology and structure of the district. To date (June 1949) a little less than one-third of the district has been mapped geologically and this work is to be continued. Petrographic investigations of the rocks by microscopic and other laboratory methods have been started and much remains to be done. Consequently this progress report is preliminary and its interpretations are tentative.

The economic results of recent investigations have in part already been made available in the publications cited above, and others are now in preparation. Additional economic information obtained during the continuing postwar investigations will appear on the final geologic map and in the final report when the district has been completely mapped. In this report, therefore, the economic geology of the district is summarized very briefly.

ACKNOWLEDGMENTS

The information compiled in this report was obtained by many coworkers and from many sources. It is literally impossible to assign detailed credit in an undertaking which has extended over so long a time and in which so many geologists have participated. The writer is pleased to acknowledge his indebtedness to all the geologists and assistants with whom he has been associated during the work in the district over the 9-year period 1940-1949. These include, during the prewar period, H. K. Dupree, T. L. Kesler, J. C. Olson, and J. J. Page; during World War II, E. Ellingwood, III, V. C. Fryklund, Jr., P. W. Gates, Jr., L. Goldthwait, W. R. Griffitts, J. B. Hadley, J. E. Husted, W. P. Irwin, R. H. Jahns, D. M. Larrabee, R. W. Lemke, J. J. Norton, J. C. Olson, J. J. Page, L. C. Pray, L. W. Seegers, W. C. Stoll, R. A. Swanson, and J. R. Wolfe, Jr.; and during the postwar period, D. A. Brobst, H. S. Johnson, Jr., J. L. Kulp, and J. A. Redden. The work has been supervised successively by G. R. Mansfield, H. M. Bannerman, R. H. Jahns, E. N. Cameron, and L. R. Page. Most of the credit for the information contained in this report should go to these men. The author of course assumes responsibility for errors and dubious interpretations.

Detailed petrographic descriptions of about 40 specimens of some of the principal rock types were prepared by D. A. Brobst. This information has been included at appropriate points in the report. Mr. Brobst also compiled the map of plate 1. Much published material has been incorporated, in part by citation and in part sub-consciously by assimilation.

The mapping has been greatly aided by the friendly cooperation of miners, mine operators, and local residents, who have freely supplied information about earlier operations, inaccessible workings, and the location of exposures hidden by vegetation. During World War II the officials and employees of the Colonial Mica Corporation gave invaluable assistance.

The Division of Mineral Resources, North Carolina Department of Conservation and Development, financed part of the work and Dr. J. L. Stuckey, State Geologist, participated in planning the work and publishing the results.

GENERAL GEOLOGY OF THE DISTRICT

ROCK TYPES

GENERAL STATEMENT

The Spruce Pine district is underlain by a considerable variety of rocks of diverse histories and complex structure. During recent large-scale mapping 14 principal varieties of bedrock have been distinguished; subvarieties and unusual phases of several of these exist. These have been divided, on the basis of modes of origin into three groups: (1) metamorphic rocks resulting from high-rank regional dynamic metamorphism; (2) metamorphic and igneous rocks that have been altered by hydrothermal solutions or by injection of magma; and (3) intrusive igneous rocks.

Most of the first group of gneisses and schists were originally a thick series of bedded rocks that apparently consisted mainly of fine-grained, water-laid sediments such as sandy shales and shaly limestones; others may have been mafic lava flows or volcanic tuffs, or sills intruded into the sediments. All of these traditionally have been assigned to the pre-Cambrian (Keith, 1905, pp. 2-3), but available evidence does not preclude their being early Paleozoic. These rocks were completely recrystallized on a regional scale by intense stress and high temperature while they were deeply buried. This metamorphism perhaps occurred in pre-Cambrian times, but it may have occurred, as suggested by King (1950, p. 16), in early or middle Paleozoic time.

The metamorphic rocks were intruded by several types of igneous masses that range in size from thin sills and dikes to large stocklike bodies. The principal intrusions are of late Paleozoic age; some may have been pre-Cambrian and some are probably Triassic.

Many of the earlier rocks were altered during the intrusion of the igneous rocks, either by the injection of fluid magma or by hot solutions or gases. Thus parts of several of the high-rank, regionally metamorphosed rocks have been transformed locally into low-rank metamorphic rocks.

In addition to the mantle of residual soil that overlies much of the area, the bedrock has been buried in many places—mainly along and near the valley bottoms—by superficial deposits of unconsolidated material. Most of these deposits have been laid down by streams, but others accumulated by gravity.

The district may be subdivided into nine areas, distinguished by differences in the predominant country rock, the structure, and the typical pegmatites. The boundaries are shown in figure 1 and the features characteristic of each area are given in Table 1. The general geology of that part of the district mapped in 1947 and 1948 is shown on plate 1. The part mapped previously has been published by Olson (1944, pl. 1).

Plate 1. Geologic map of part of the Spruce Pine district, North Carolina. In Pocket.

TABLE 1.—SUBDIVISIONS OF THE SPRUCE PINE DISTRICT[1]

Area	*Predominant country rock*	*Predominant structure*	*Typical pegmatites*	*Economic products from pegmatites*
Plumtree	Hornblende gneiss (and mica gneiss).	Low, variable dips.	Thin lenses in series; many elongate. Medium- and coarse-grained.	Brown, reddish, and green sheet mica (Potash block spar).
Ingalls	Injection gneiss	Moderate, variable dips.	Stocks, thick dikes, and sills. Fine- to coarse-grained.	Kaolin Ground mica Potash block spar Green sheet mica; "A" structure
Spruce Pine	Injection gneiss	Moderate to high dips in all directions.	Irregular stocks, thick sills, and dikes. Fine- to coarse-grained.	Soda spar (flotation) Potash block spar Kaolin Green and brown sheet mica; "A" structure Ground mica
Crabtree Creek	Injection gneiss	Moderate to high dips in all directions.	Irregular stocks, very thick sills, and dikes. Fine- to coarse-grained.	Potash block spar Soda block spar Green—"A" structure (and brown) sheet mica; stained (Ground mica)
Ledger-Kona-Micaville	Mica gneiss, injection gneiss.	High to moderate dips to southeast.	Thick, irregular sills, and stocks. Fine- to coarse-grained.	Soda spar (flotation) Potash block spar Soda block spar Ground mica Brown, green (and reddish) sheet mica; stained (Kaolin)
South Toe River	Injection gneiss and mica gneiss.	Moderate to high dips to southeast and southwest.	Thin gently plunging elongate lenses. Medium- to coarse-grained.	Brown, green (and reddish) sheet mica; stained Ground mica Potash block spar Soda block spar
Hawk-Bandana-Shoal Creek	Mica gneiss and hornblende gneiss.	High dips to southeast.	Sills and thin lenses in series. Medium- to coarse-grained.	Reddish, brown (and green) sheet mica (Potash block spar) (Soda block spar)
Green Mountain	Mica gneiss and hornblende gneiss.	Moderate to high dips to southeast.	Thin sills. Medium to coarse-grained.	Brown and green sheet mica; stained (Potash block spar) (Soda block spar)
Black Mountains	Mica gneiss and hornblende gneiss.	Steep dips to northwest, southwest, and southeast.	Thin to thick sills; steeply plunging pipes. Medium- to coarse-grained.	Reddish sheet mica; "A" structure (Potash block spar)

[1] Stained mica or "A" structure noted only where common. Potash spar (perthitic microcline) is hand-sorted as blocks from coarse pegmatite. Soda spar (plagioclase) is in part produced similarly (block spar) but most is separated with admixed potash spar by froth flotation. Ground mica includes small flakes obtained from kaolinized fine-grained pegmatite and larger books too defective to yield sheet mica. Items are listed in order of estimated abundance or importance; minor items in ().

METAMORPHIC ROCKS

Mica gneiss.—Mica gneiss is probably the most abundant metamorphic rock in the district, and is predominant or fairly common in all subdivisions. Ordinarily it is interbedded with hornblende gneiss in layers ranging in thickness from a fraction of an inch to scores of feet, but in places it forms unbroken masses several hundred feet thick. Dikes and sills of pegmatite, and quartz veins are common. The foliation in places is nearly planar, but elsewhere it has been gently warped or closely folded.

The typical rock is a moderately fine-grained even-textured gneiss composed of layers of quartz and feldspar alternating with layers of muscovite and biotite. Mica is sufficiently abundant in places to render the rock schistose. Either muscovite or biotite may locally dominate to the practical exclusion of the other. The banding is commonly regular, and quite thin layers may persist long distances. The feldspar in most specimens is oligoclase or sodic andesine; microcline is uncommon. Biotite is partly altered to chlorite. Small red garnets (0.5 to 2.0 mm in diameter) are common and in places are very abundant. Kyanite needles and blades are especially abundant in a northeast-trending belt near Bandana in Mitchell County and also over most of the Black Mountains area. Some layers of gneiss are exceedingly rich in kyanite and have blades as much as 4 inches long. Common minor constituents include magnetite, allanite, clinozoisite, zircon, apatite, sphene, rutile, leucoxene, and pyrite. In some places quartz seems to have crowded aside and invaded the micas, suggesting it may have been introduced. Thin streaks of graphite in mica gneiss were noted at the Carson Rock mine in Yancey County.

Mica gneiss weathers to light or moderately dark brown soil that is sandy and is rich in tiny flakes of muscovite and bleached biotite. Because mica is unaltered even in gneiss where the feldspar has been entirely weathered to clay, decomposed gneiss has a misleading appearance and may be mistaken for mica schist where only the foliation surfaces are observed; its true character is most apparent on cross breaks.

The common regularity of the lamination of mica gneiss, its mineral composition, and the fact of its being interbedded with marble at one locality indicate a sedimentary origin for much of it. Presumably it was originally sandy shale. These deposits may have been formed during pre-Cambrian or possibly during early Paleozoic time. Regional dynamic metamorphism transformed the sediment to its present condition during a pre-Cambrian or Paleozoic orogeny.

Mica gneiss was the principal rock type included by Keith (1903, p. 2) in the Carolina formation on his geologic quadrangle maps.

Muscovite schist.—Bands of muscovite schist ranging in thickness from a few feet to about 600 feet are interbedded with mica gneiss in several parts of the district. It crops out in several narrow strips near Bandana in Mitchell County and near Blue Rock church in Yancey County, as well as elsewhere in the district.

The rock is relatively coarse textured. Muscovite, the dominant mineral, occurs in flakes commonly a quarter of an inch wide. In places a little biotite is associated with the muscovite. Small quartz grains and minor amounts of feldspar probably constitute about a quarter of the rock. The schist grades into mica gneiss by increase in the abundance of feldspathic layers. Red garnet crystals ranging from 0.02 to 0.5 inch in diameter generally are abundant. Kyanite occurs in the Bandana area, and small black tourmaline prisms were observed in the schist near quartz and pegmatite stringers along the highway 1½ miles south of Bakersville. Muscovite schist weathers to a light-brown soil in which coarse, yellow, iron-stained muscovite flakes are abundant.

Muscovite schist probably was formed by metamorphism of the more shaly layers in the sedimentary series, which gave rise to mica gneiss. It, like the mica gneiss, was included by Keith in his Carolina formation.

Dolomitic marble.—Coarsely crystalline dolomitic marble is interbedded with mica gneiss along lower Sinkhole Creek in Mitchell County. It can be traced about 1700 feet northeast from the Toe River but is not known to the southwest. No other marble is known in the district. Apparently there are two layers, about 10 and 40 feet thick, separated by about 20 feet of mica gneiss; but the structure has been so disturbed by faulting and by the intrusion of an irregular, crosscutting pegmatite that perhaps one layer has been repeated. Individual grains of dolomite are as much as 0.3 inch across. The magnesia content of a sample is reported by Hunter[1] to be nearly as high as that of the mineral dolomite.

Hornblende gneiss, hornblende schist, and amphibolite.—Gneisses, schists, and amphibolites composed largely of hornblende are abundant in the Spruce Pine district. They are probably second in abundance—possibly even first—among the foliated rocks. They are common in all parts of the district and ordinarily are interbedded with mica gneiss or schist. In the northeastern part of the district especially, in Avery County, these rocks are several thousand feet thick and are almost free of other, interbedded rocks. The type locality of the Roan formation of Keith (1903, p. 2)—comprising mainly hornblendic rock—is just north of the district in Roan Mountain. Another area underlain almost exclusively by hornblendic rock extends north and northwest from Estatoe to the North Toe River, and includes Simmons Knob and Baileys Peak.

The hornblendic rocks form layers from a fraction of an inch to many feet in thickness that are generally interbedded with mica gneiss or schist. As in the mica gneiss, the foliation may be planar, warped, or tightly crumpled. Where hornblendic and micaceous gneisses are interbedded, the bedding and foliation of both are strictly parallel; no definite crosscutting relations have been seen. Keith (1903, p.2) reports that the Roan formation "appears to cut the Carolina gneiss" but that the contacts have been so metamorphosed that proof of the relationship is impossible. Regular joint fractures are more common in the hornblende gneiss and schist than in the less brittle mica gneiss.

The hornblendic rocks include (1) distinctly banded gneisses with alternating hornblendic and feldspathic layers, (2) schistose rock consisting almost exclusively of fine to coarse hornblende needles with roughly parallel orientations, and (3) nearly massive amphibolites that lack distinct foliation and consist dominantly of feldspar and quartz. The gneisses and schists are black to dark green, and are medium to fairly coarse grained. The hornblende needles, which range from about 1 to 20 mm in length, are in parallel planes, but linear parallelism in these planes is not common. The gneisses and schists grade into one another by variation in feldspar content. Most of the feldspar is oligoclase or andesine. In some phases feldspar forms elongate, augenlike lenses. Quartz ordinarily composes 10 to 20 per cent of the rock but rarely may compose nearly 50 percent. Garnet is ordinarily less abundant than in mica gneiss but in places forms lenses half an inch thick. On Fawn Mountain in Yancey County garnet crystals as much as half an inch in diameter locally compose more than half of the rock. Biotite and chlorite in places, especially in the vicinity of pegmatitic bodies, are mixed with hornblende and form as much as a quarter of the rock; these minerals, as well as epidote and allanite, formed by alteration of hornblende. Thin layers and veinlets of epidote are common. Other minor constituents include magnetite, ilmenite, pyrite, chalcopyrite, sphene, rutile, zircon, apatite, and leucoxene. Staurolite was observed in a garnet-rich specimen from Upper Blue Rock Branch valley.

Associated and interbedded with the hornblendic gneisses and schists are other similar gray to green rocks in which actinolite-tremolite and possibly anthophyllite take the place of hornblende.

These rocks have been noted in the Boonford, Kona, Double Island, and Bandana areas. In some of these rocks scattered grains of carbonate are cut and embayed by tremolite and chlorite.

The more massive amphibolite, described by Olson (1944, p.19) is fine-grained and is commonly light brown or yellow. It is much less abundant than the other two rock types and occurs in relatively thin layers interbedded with hornblende gneiss or schist.

The hornblendic rocks decompose to a dark-brown, commonly a reddish-brown, very plastic, heavy, and generally grit-free soil. Partly decomposed fragments resemble old weathered bricks. These soils resemble those derived from diabase, but may be distinguished by the traces of foliation and by the residual boulders in the subsoil.

The Roan formation (hornblendic rocks) was believed by Keith (1903, p.2) to be intrusive into the Carolina gneiss and thus younger, though also of pre-Cambrian age. The only observation made by the writer that might possibly support this view is a relationship noted near a small creek just south of the Carolina Mineral Company No. 20 mine in upper Crabtree Creek valley. Here a layer of hornblende gneiss

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[1]Hunter, C. E., oral communication.

about a foot thick and enclosed in mica schist ends abruptly in a flat surface perpendicular to the bedding; the foliation of the schist bends sharply around the square end of this layer. Though this relationship might have resulted from intrusion, it can also be interpreted as a deformational feature. The outstanding feature of the hornblendic rocks is the regularity of the layering where they are interbedded with mica gneiss. Even very thin layers persist long distances. In an outcrop along the South Toe River about 2 miles north of Micaville, 10 bands of alternating mica and hornblende gneiss are exposed in a distance of 4.64 inches across the layering. The layers range in thickness from 0.04 inch to 1.22 inches. All but one of these thin layers are continuous with almost uniform thickness the full length of the exposure, a distance of about 4 feet. Such uniformity and persistence of layering suggest a sedimentary origin. Gradation of grain size across a single hornblende gneiss bed has been observed. These thin, interbedded hornblende gneisses and the actinolite-tremolite rocks may have been impure dolomitic limestones. The mafic mineralogic composition, however, coupled with the conformable relations to mica gneiss, has led most workers to believe that the ordinary hornblende rocks are metamorphosed mafic volcanic extrusives, and perhaps, in part at least, are conformable intrusive sills. Chemical data are lacking and the relationship to the marble is not known. Consequently, origin is still in doubt. Perhaps some of the hornblendic rocks are sedimentary in origin and some are igneous.

IGNEOUS ROCKS

Dunite.—Intrusive masses of dunite in the Spruce Pine district are known in the vicinity of Frank in Avery County, on Mine Creek and Whiteoak Creek south and southeast of Bakersville in Mitchell County, and on Mine Branch near Newdale and on Mine Fork north of Burnsville in Yancey County. They have been investigated by Hunter (1941) and by Hunter, Murdock, and MacCarthy (1942).

In plan the dunite masses are irregularly round or elliptical, and are as much as 2000 feet long. They commonly cut across the foliation of the enclosing gneisses.

The dunite is medium- to coarse-grained, and consists mainly of olivine with accessory enstatite and chromite, as well as the alteration products antigorite, talc, tremolite, and chlorite. It weathers to an exceedingly infertile, gray-brown soil and is characteristically exposed on rocky surfaces nearly barren of vegetation.

The dunite bodies have not undergone the regional dynamic metamorphism that has affected the older gneisses and schists which they intrude. The Newdale mass seems to have been intruded by pegmatite, though the contacts are not well enough exposed for the relationship to be certain. Hunter (1941, pp. 61-62), however, reports that several pegmatites cut the Democrat dunite body in Buncombe County just southwest of the Spruce Pine district. Dunite has been greatly affected by hydrothermal solutions, which may have been related to the pegmatites. Consequently, the dunite intrusives are considered to be younger than the mica and hornblende gneisses and schists and older than the late Paleozoic (?) silicic intrusives.

Pyroxenite.—Ultramafic rocks underlie small areas scattered throughout the district. Most of these have been considerably altered so that their original composition is in doubt. They seem to have been largely pyroxenite, but they probably also include peridotites. At present they consist mainly of soapstone and/or asbestos rock, and are described under those headings.

At the J. W. Autry mica mine a mile southeast of Burnsville there is a small mass of coarse-grained, black pyroxenite which is almost unaltered.

The age of pyroxenite is probably similar to that of dunite, and the two rocks may be variants from the same magma. Both have been greatly altered by hydrothermal solutions apparently derived from the pegmatitic intrusives, but they have not been regionally metamorphosed.

Pegmatite.—A large variety of closely related silicic igneous bodies, ranging from very large stocklike granitic masses, through large and small pegmatite sills, lenses, and dikes, to quartz veins, intrude most of the rocks of the Spruce Pine district. Slightly younger aplite dikes are probably part of the same series. These intrusives, collectively called pegmatite in the present report, are distributed generally though unevenly over the district. Large bodies of fine-grained pegmatite ("alaskite" and "granite" of other reports) are commonest along the southeast side of the district in the Ingalls, Spruce Pine, and Crabtree areas especially. (See Table 1 and Figure 1.) The coarser-grained pegmatite occupies a curved belt 4 to 6 miles wide on the north, northwest, and southwest sides. Almost no pegmatite bodies occur southeast of the big fine-grained pegmatite masses. Within the district several areas contain almost no pegmatite.

The pegmatites consist primarily of various proportions of plagioclase, quartz, perthitic microcline, and muscovite. On the average it is estimated that plagioclase forms about 45 per cent of the rock, quartz about 25 per cent, microcline about 20 per cent, and muscovite about 10 per cent. Microcline is lacking in many pegmatites or pegmatite units and muscovite is low or is lacking in a few; plagioclase and quartz are nearly ubiquitous. The plagioclase is mostly oligoclase but ranges, according to Maurice (1940, p. 160), from Ab_{94} to Ab_{70}. A tentative classification of the pegmatites used in current areal mapping groups the possible combinations of the principal constituents into major types depending on the mineral proportions. Four types were mapped, as follows: (1) plagioclase-quartz-muscovite pegmatite, (2) plagioclase-quartz pegmatite, (3) plagioclase-quartz-perthite-muscovite pegmatite, and (4) perthite-quartz-plagioclase-muscovite.[1] A quantitative estimate of the proportions of the essential minerals was made for each pegmatite examined, and the relative order of abundance is given in the name. In addition to the essential minerals, the pegmatites commonly contain garnet, biotite, and apatite in small quantities, and still less commonly beryl, tourmaline, epidote, allanite, thulite, various sulphides, tantalite-columbite, and uranium minerals.

Pegmatite weathers to light-colored sandy soils. It is distinguished by abundant quartz, partly in large blocks, very small amounts of iron stain, and large quantities of muscovite in small or large flat flakes.

In the early reports by Keith (1903; 1905; 1907) the silicic intrusives were referred to as granite and pegmatite, and were mapped with the Carolina gneiss. Later Watts (1913, p. 106) distinguished granite from pegmatite in the district, but the difference was not generally appreciated. Hunter (1940, p. 98) introduced F. L. Hess' term "alaskite" for the finer-grained granitic rock (average grain diameter, 0.25 to 0.5 inch) occurring in large irregular bodies, as distinguished from the coarse pegmatite that forms smaller sills and dikes. This called attention to an economically important difference, inasmuch as the "alaskite" bodies by supergene decomposition had become deposits of residual kaolin with very large reserves as compared with the small deposits worked during the earlier days of the clay industry, which were derived from coarser and smaller pegmatite sills and dikes. The term "alaskite" has been rather widely adopted in the district but is not retained here because the dominant feldspar does not correspond to that of the rock type to which the name was originally applied (see Spurr, 1900, p. 231).

The finer-grained pegmatite has also been referred to as granite, granodiorite, and leucotonalite. The term "granite" is objectionable because the dominant feldspar is not microcline, orthoclase, or albite but is mostly oligoclase. The remarkably low iron content (averaging less than 1 per cent) and the high silica content (about 75 per cent) show a resemblance to granite. The virtual absence of mafic minerals was the reason for Hess and Hunter's proposal (Hunter, 1940, p. 98) of "alaskite." Granodiorite or leucotonalite or quartz monzonite and quartz diorite are not entirely satisfactory names because the silica is too high, the iron too low, and the plagioclase too sodic for typical rocks in these categories. The texture of the Spruce Pine rock, though finer grained than that of typical pegmatite mined for feldspar and mica, is still much coarser than that of average granite or granodiorite; most of the grains are half an inch across and many are more than an inch. Thus, though the terms "granodiorite," "leucotonalite," and "leucoadamellite" may be mineralogically correct, they may be misleading. For these various reasons it is thought best to refer to "alaskite," "granite," or "granodiorite" as leucogranodioritic, fine-grained pegmatite.

Though a practical difference does exist between the larger bodies of finer-grained rock that yield kaolin in commercial quantities and the smaller bodies of coarser rock that are sources of hand-picked feldspar and sheet mica, yet the gradations in texture and mineral composition between these two extremes indicate that the finer- and the coarser-grained bodies must have resulted from local variations in the crystallization of the same magma. The large "alaskite" bodies contain irregular parts of more coarsely pegmatitic texture from which block spar and book mica may be obtained; the contacts between these parts are so completely gradational that no line can be drawn between them. In fact, many of the largest and most valuable pegmatites from which feldspar has been mined, as at the Gusher Knob and Deer Park mines, have "walls" of "alaskite" into which they grade by decreasing grain size. Conversely, in many rather small mica-bearing pegmatites there are zones of rock identical in texture and composition with the "alaskite" and grading in-

[1]It has not proved feasible to show these types separately on the geologic map, plate 1.

sensibly into typical coarse pegmatite. For these reasons, during recent field work by the U. S. Geological Survey, both types have been considered variants of a single rock, to which the name pegmatite is applied. The different pegmatites are distinguished by textural and mineralogical modifiers.

Individual mineral grains in the pegmatites range from about 0.1 inch to about 6 feet in thickness. Those pegmatites or pegmatite units in which more than half the rock consists of grains half an inch thick or less are referred to as fine-grained; where more than half ranges between half an inch and 6 inches, as medium-grained; and where more than half exceeds 6 inches, as coarse-grained. All of the minerals may occur in grains near the lower size limit. Masses of plagioclase attain a maximum thickness of about a foot, and subhedral crystals of microcline about 6 feet. Quartz forms solid masses of small grains as much as 20 feet thick. Muscovite books more than a foot wide are uncommon; the largest obtained in the district, taken many years ago from the Fannie Gouge Mine, is said to have weighed 4300 pounds.

In some pegmatites the grain size is rather uniform, except for a slight increase in average grain size from the wall inward, but in others great differences in texture exist from one part to another. Some pegmatites have lenticular masses of microcline a foot or more long scattered through rock averaging half an inch in grain size. Many have a rude foliation resulting from the parallel orientation of mica flakes and elongate masses of feldspar or quartz.

Nearly half of the pegmatites in the Spruce Pine district are essentially homogeneous in mineral composition and texture. The remainder comprise several rock units. The most common units are called zones, and are distinguished by contrasting mineralogy or texture or both. These zones are roughly concentric shells around a central core; the outside shape of each roughly approximates that of the whole pegmatite. The simplest type of zoned pegmatite has two zones—a thin border zone of distinctly finer grain and a coarse-grained core—both commonly consisting of plagioclase, quartz, and muscovite. A little more than a quarter of the pegmatites carefully investigated had three or more zones. The cores are commonly of massive quartz or of coarse perthitic microcline and quartz, the wall zones are of plagioclase-quartz-muscovite rock, and the border zones are of finer-grained rock of similar composition.

In addition to zones, which are considered to be primary units formed during the crystallization of the pegmatitic fluid, some pegmatites have rock units formed by the filling of fractures with later pegmatitic material, and a very few have units resulting from replacement of earlier rock by hydrothermal solutions derived from pegmatitic fluids.

A detailed description of the internal structure of pegmatites generally, with many references to those in the Spruce Pine district, may be found in a paper by Cameron, Jahns, McNair, and Page (1949).

The variety of form of the pegmatites is very great. Fine-grained pegmatite forms very large masses whose shapes in plan are highly irregular and whose extensions in depth are entirely unknown. They may be stocks or huge sills. They tend to be elongated northeastward and are as much as 2 miles long and a mile wide. Numerous sills, dikes, and stringers extend from them. Inclusions of country rock, ranging from a fraction of an inch to scores of feet in thickness, are common within them, especially near the contacts. The inclusions are commonly slablike and tend to parallel the walls, but irregular masses and discordant orientations are numerous.

Typical coarse-grained pegmatite forms smaller bodies which, though irregular, tend to be tabular or lenticular. At least three-quarters of these are conformable to the foliation of the enclosing gneisses. They include thin tabular sills, pinch-and-swell sills, irregular thick sills, more or less discoidal lenses, considerably elongate lenses, and irregular pipelike masses. Elongate lenticular pegmatites plunge parallel to the axes of neighboring minor folds, generally at moderate angles to the south or southwest. The discordant bodies range from tabular to lenticular to irregular. The coarse pegmatites range in thickness from a few inches to more than a hundred feet.

The age of the pegmatitic intrusives probably is late Paleozoic. Radioactive determinations (Holmes, 1931, pp. 342-344; Alter and McColley, 1942, p. 213) on uranium minerals have given various ages ranging from 251 million to about 370 million years. A thorium determination (Bliss, 1942, p. 215) on monazite, however, gave 600 million years, presumably pre-Cambrian.

Aplite.—Small dikes of aplite are fairly common in the western part of the district and less common elsewhere. The rock is quite fine grained (averaging 1/50 inch) and is composed of oligoclase, quartz, and muscovite or biotite. It is usually equigranular, though some is porphyritic. Much is plainly foliated, with small green muscovite flakes aligned parallel to the dike walls. Minor accessory and secondary minerals include apatite, rutile, sphene, zircon, chlorite, sericite, and epidote. The dikes cut across pegmatites and have sharp contacts with both pegmatite and the metamorphic rocks. Though distinctly later than pegmatite, they probably represent the same magmatic invasion.

A large body of apparently similar rock has been mined on a small scale for halloysite clay on the northeast slope of Carters Ridge 1½ miles southeast of Spruce Pine. The body trends roughly north and is at least 40 feet thick and 150 feet long. It consists almost wholly of fine-grained feldspar, with little muscovite and apparently no quartz. The feldspar has been completely kaolinized to depths of more than 25 feet, forming a very plastic, grit-free, white clay. Paralleling the body just to the west is a ledge of massive quartz at least 20 feet thick that crops out for a distance of about a hundred yards. This deposit has recently been investigated by Hunter and Hash (1949, pp. 10-14).

Basalt.—Thin dikes of basalt cut pegmatites and their wall rocks at several places in the Plumtree area in Avery County. The dikes consist of labradorite, augite, and olivine in part altered to serpentine. They are fine-grained to aphanitic and in part at least have ophitic texture. Veins of calcite, zeolites, and sulphides are associated with the dikes. Keith (1905, pp. 5-6; 1907, pp. 7-8) mapped similar gabbro just north and northwest of the Spruce Pine district. Petrographic similarity to the late Triassic dikes and sills (see Campbell and Kimball, 1923, p. 45; Prouty, 1931, pp. 480-481; Reinemund, 1949) in the North Carolina Piedmont indicates that the basalt dikes in the Spruce Pine district are also Triassic in age.

ALTERED METAMORPHIC AND IGNEOUS ROCKS

Mica injection gneiss.—Mica injection gneiss occurs in wide areas around the large intrusives of fine-grained pegmatite, where granitic material has been injected into and has permeated mica schist and to a lesser extent mica gneiss, and even hornblende gneiss and schist. This rock is most abundant along the southeast side of the district, especially near the large intrusives of the Spruce Pine and Crabtree Creek areas, and in the northern part of the South Toe River valley. The large Brushy Creek and Threemile Creek intrusives in Avery County have produced thinner and less extensive injection gneiss, apparently because of the preponderance of hornblende gneiss over mica schist in this part of the district.

Mica injection gneiss is coarse grained and is characterized by silvery muscovite flakes separating and enclosing small pods of feldspar and quartz. On surfaces parallel to the foliation the rock looks like mica schist, but on cross breaks the dominance of feldspar and quartz is apparent. Veins of quartz and stringers of pegmatite abound. The feldspar is oligoclase or andesine (An_{12} to An_{40}) and composes 20 to 50 per cent of the rock; quartz is in reciprocal amounts. Muscovite is the usual mica but commonly biotite is abundant and locally is predominant. Minor constituents include apatite, sphene, magnetite, zircon, staurolite, allanite, clinozoisite, chlorite, and pyrite. Textural relationships observed under the microscope, such as crumpled mica foliae and inclusions of mica in quartz and feldspar, tend to confirm the field interpretation of the origin of this rock. Much of the rock, especially that associated with hornblendic rocks, is highly garnetiferous. Near some intrusives the mica foliae are separated into shreds isolated in feldspar and quartz, and the injection gneiss grades into normal fine-grained pegmatite. At greater distances from the intrusive the amount of injected material may be so small that the typically lumpy foliation is not developed and the injection gneiss grades into normal schist or gneiss.

Injection gneiss weathers to light-yellow sandy soil much like that derived from fine-grained pegmatite. It may ordinarily be distinguished by the presence of curved bunches of muscovite flakes in the soil, rather than the flat and coarser mica flakes yielded by pegmatite. In many places, however, the amount of introduced material is so great that, if exposures are poor, doubt exists as to whether the area is underlain by injection gneiss or pegmatite.

This distinctive kind of mica gneiss, or migmatite, is partly of metamorphic and partly of igneous origin. The injection of magmatic material between the foliation planes was accompanied by partial solution and recrystallization of the original constituents of the rock. Mica schist seems to have been the most readily injected of the earlier rocks. Practically every exposure of mica schist shows at least a little introduced material. The hornblendic rocks evidently were less permeable than schistose micaceous ones, as unaltered layers remain in the injection gneiss formed from hornblende schist and gneiss. In places, however, hornblende gneiss or schist has been intruded lit-par-lit and the hornblende changed to biotite. These injection gneisses are rich in biotite. Where the change was not complete, red garnets are common in the altered part and lacking in the original. Elsewhere only metacrysts of feldspar or eye-shaped spots of feldspar or granitic material were added to hornblende schist.

Chloritic amphibolite.—Complexly metamorphosed, nonfoliated amphibolite characterized by curved plumose aggregates of chlorite or actinolite underlies wide areas in upper Brushy Creek valley near Estatoe in Mitchell County and extends northeastward beyond Penland. Smaller areas were observed near Rockhouse Creek in Grassy Creek valley, near Bear Creek Church, and just west of Crabtree Creek north of U. S. Highway 19-E. These amphibolite bands range in thickness from a few feet to at least a third of a mile, and invariably are adjacent to hornblende gneiss or schist on at least one side. Within the amphibolite are numerous masses of hornblende gneiss or schist with greatly contorted foliation, suggesting that the amphibolite was derived from such hornblendic rocks. Some exposures contain closely packed ellipsoidal masses, a few inches to 2 or 3 feet thick which resemble pillow structure of lava.

The chloritic amphibolite is exceedingly variable in character from place to place. Most of it is essentially massive, but in places it shows contorted foliation. In the typically massive rock curved sheaves and veinlets of chlorite or actinolite divide the rock into rough lenses from half an inch to 3 or 4 inches thick. These lumpy masses consist mainly of fine-grained plagioclase (oligoclase or andesine) and quartz with minor amounts of hornblende, biotite, and garnet. The ends of the curved sheaves of chlorite and actinolite fray out into the feldspathic part. Faint parallel orientation of biotite and hornblende is observed in thin sections of some of the feldspathic, fine-grained material. Other parts of this rock consist of irregularly matted aggregates of dark amphibole needles and fine-grained micaceous minerals, apparently including biotite, chlorite, and muscovite or possibly talc, with very little feldspar and quartz. In places irregular bodies of massive quartz—possibly quartzite—occur. Sulphide minerals, principally pyrite and pyrrhotite, are abundant and in the fine-grained feldspathic parts may form as much as 1 or 2 per cent of the rock. Outcrops are knobby because of the curved surfaces of chlorite and are pitted and heavily iron-stained from weathering of the sulphides. The dark-brown plastic soil derived from chloritic amphibolite closely resembles the soil formed from hornblende gneiss and schist.

Detailed petrographic information is not available and therefore, the origin of this rock is not well understood. The chloritic amphibolite is perhaps migmatitic rock derived from hornblende gneiss by profound physical and chemical alteration. The intense contortion of the foliation indicates local deformation. The ellipsoidal masses resembling pillow lava probably are broken gneiss fragments in a wide fault zone, somewhat rounded by abrasion during displacement and by subsequent chemical alteration. The brecciated rock apparently was altered by hydrothermal solutions and probably also by the injection of aplitic magma. The fine-grained feldspathic parts seem to represent aplitic material added to the original constituents that were recrystallized by hot solutions or magmatic fluids to form actinolite and chlorite.

Chlorite-biotite schist.—Chlorite-biotite schist occurs in eastern Mitchell County on the northeast end of Tempa Mountain and on Hanging Rock Knob three-quarters of a mile to the north, and in Avery County on the east side of the North Toe River at the mouth of Brushy Creek. This schist forms irregularly lenticular, conformable layers, one to about 20 feet thick, in mica injection gneiss. The schist is closely crumpled in small and large sigmoid, chevron, and irregular folds. In the micaceous rock are numerous relic strips of hornblende gneiss and schist in which some amphibole crystals are as much as 8 inches long and half an inch thick. The schist layers are irregularly and complexly veined by quartz and fine-grained pegmatite similar to that in the mica injection gneiss. The schist consists mainly of chlorite and biotite, with long hornblende needles, fine-grained talc, minor quartz, feldspar, apatite, and sulphides. It contains hundreds of ellipsoidal, spheroidal, and irregular bodies ranging from an inch to 6 feet in diameter and from a quarter of an inch to 18 inches in thickness. Most of these ellipsoids are composed of hornblende schist, in which much of the hornblende is in needles 3 or 4 inches long. Others consist of subhedral white and smoky quartz crystals irregularly packed together. These bodies are conformable to the foliation of the schist, and some grade laterally and longitudinally from hornblende schist into chlorite-biotite schist. Others, especially the quartz ellipsoids, have sharp boundaries. Though the shape of the ellipsoids might suggest an origin from pillow lava, the composition of the quartz ellipsoids, and the gradational contacts of the hornblendic ones, together with their association with hornblende gneiss layers, seem unfavorable to the possibility.

Weathering bleaches and iron-stains the rock so that near the surface it is dull brown instead of glassy green and black.

Microscopic examination reveals the presence of titanite, magnetite (?), and zircon inclusions in hornblende and biotite. In places carbonate forms a fifth of the rock. In some specimens chlorite predominates and in others biotite. The feldspar is mainly oligoclase, though some orthoclase appears to be present. Hornblende has been altered to interleaved biotite and chlorite, which appear in part to be contemporaneous. Elsewhere chlorite and some talc seem to be secondary after biotite. Quartz and feldspar replace hornblende and biotite; quartz and carbonate replace feldspar.

This schist apparently was formed through hydrothermal alteration of hornblende-rich rocks by solutions coming from underlying pegmatite magma. To form biotite presumably some potash had to be introduced. The large number of ellipsoids and veins of quartz seems to indicate that the solutions were siliceous, though silica would have been released by the change of hornblende to biotite. Carbonate indicates the addition of carbon dioxide. The result was mainly a recrystallization of the original material into new minerals, and to a lesser extent the development of larger grains of original minerals such as hornblende.

Chlorite-biotite schist is distinguished from chloritic amphibolite by its strongly schistose texture and predominance of micaceous minerals. The amphibolite is largely massive, the only well-foliated parts being hornblende gneiss; chlorite is a characteristic but not a dominant mineral.

Soapstone and talcose schist.—Bodies of impure soapstone and talcose schist are numerous in the Spruce Pine district. They are distributed rather generally over the district and most are relatively small. They have been derived from dunite and hornblende gneiss, and possibly from pyroxenite.

The dunite bodies, previously described, have to a considerable extent been altered. The bulk of some bodies now consists largely of serpentine rather than the original olivine. Near their outer edges, however, talc schist or soapstone has been commonly formed. In fact, Hunter (1941, pp. 45, 50, 54) shows a talc-vermiculite fringe, which is commonly schistose and slickensided, around all the dunite bodies. The impure soapstone bodies in the Grassy Creek area in Mitchell County, which occur within fine-grained pegmatite, apparently as inclusions, are reported by Olson (1944, p. 22) to have centers of dunite.

Most of the soapstone in the Spruce Pine district, however, seems to have been formed by alteration of hornblende gneiss. Small bodies of impure soapstone, mostly from about 5 to 25 feet thick, are numerous throughout the district within areas of hornblende gneiss. The largest body mapped is on the east side of Crabtree Creek about half a mile northwest of Crabtree Falls. In many places the gneiss can be traced along strike into soapstone that may retain the foliation of the gneiss. Much of the rock is fine grained and massive but in places it is rather schistose. Actinolite, chlorite, serpentine, and vermiculite commonly are mixed with the talc. Soapstone is resistant to local weathering and commonly crops out conspicuously. Loose fragments of the rock are numerous in the overlying soil.

The talcose rocks have been formed by local secondary hydrothermal alteration of rocks rich in magnesian minerals. Olivine and hornblende by hydration have been converted into talc, commonly with associated serpentine, chlorite, and actinolite. This probably was caused by solutions emanating from the pegmatitic intrusions.

Asbestos rock.—Amphibole asbestos rock occurs in at least half a dozen places in the Spruce Pine district, mainly in Yancey County. Probably the best deposits are that on a ridge 1 mile northeast of Micaville near the Googrock mine and that on the northwest side of the South Toe River opposite the mouth of Blue Rock Branch. The latter deposit occurs in a band of hornblende gneiss, from which it evidently was derived, and forms an irregular zone some 20 feet wide trending northeast parallel to the local foliation. The rock consists in part of matted groups of diverging amphibole blades or coarse needles from 0.5 inch to 6.0 inches long, and in part of closely packed rosettes or radiating groups of finer fibers 0.5 to 1.0 inch long. A small deposit half a mile west of Young's Chapel in Yancey County contains gently dipping irregular veins that strike about perpendicular to the foliation and are composed of cross fibers as much as 38 inches long. Amphibole asbestos has also been formed along the contact between the Newdale dunite body and hornblende gneiss. Small amounts of actinolite, talc, and chlorite occur in most deposits.

Chrysotile asbestos is reported by Hunter (1941, p. 57) in the Whiteoak Creek dunite mass a mile southeast of Bakersville.

The asbestos deposits have not been studied in detail, but they seem to have resulted from local hydrothermal alteration of mafic rocks, mainly hornblende gneiss.

SUPERFICIAL DEPOSITS

Terrace deposits.—Old erosion surfaces throughout the district are represented by flat-topped ridges and adjacent gently rolling country along the rivers and larger tributaries. These are about 50 to 200 feet above the present valley bottoms. Most of these fairly level, elevated areas are underlain by unconsolidated stream sediment that rests unconformably on the eroded edges of the various bedrock formations. The lowest few feet of this capping of sediment is commonly gravel, in places containing well-rounded boulders more than a foot in diameter. The bulk of the deposit is brown silt and clay, with recurrent layers of sand and gravel. The deposit is heavily stained and in part is loosely cemented by iron oxide. Its maximum thickness is about 30 feet, but the thickness may vary considerably in any one deposit. Stratification is quite irregular; scour and fill or cross-bedding are common.

These deposits are the remnants of old floodplain alluvium, laid down when the whole region was at a lower elevation and before the streams had worn down to their present levels. Regional uplift in stages has allowed the formation of at least three terrace levels, each uplift causing the streams to destroy part of the higher deposits. The ages of the several high-level deposits are not known; they are probably all Pleistocene or at the oldest Pliocene.

Floodplain alluvium.—All of the larger streams have by lateral erosion developed flat floodplains along much of their length that range in width from only a few feet to a quarter of a mile. These flat bottom lands are underlain by gravel, sand, and impure clay that probably range in thickness from about 5 to 10 feet. This sediment lies unconformably on the eroded bedrock formations, completely burying them except for occasional exposures in the stream channels. These deposits are of very recent origin.

Closely related to floodplain alluvium are the comparatively large alluvial-fan deposits made by the steeper tributaries where they pass off the mountain sides into the valley bottoms. The upper surfaces of these slope gently but irregularly toward the main valley and are crossed by numerous abandoned stream channels. The deposits consist of poorly sorted gravel, sand, and clay and contain many boulders of large size. They merge into the flat floodplain deposits at their outer edges. Large areas along the lower mountain slopes are mantled with this material. An especially large one has been formed by Jones Creek a mile north of Ingalls in Avery County.

Talus and landslide deposits.—Talus and landslide deposits occur along the lower parts of many steep mountain slopes, as on the east side of Buck Hill Mountain in Avery County. These deposits of broken and weathered rock, now largely decomposed to soil, have crept, slid, or fallen into their present positions mainly by the influence of gravity. They are not related to any present-day stream but form where the mountain side is concave outward. Temporary runoff in such broad hollows was doubtless an important factor in the transportation of this material, but it probably moved mainly by flowing and sliding downhill when thoroughly wet. The upper surface slopes gently to rather steeply and is commonly hummocky. Extremely large masses of rock, large enough to be mistaken for outcrops of the bedrock, are included. The thickness of the talus and landslide material is not known, but topographic evidence indicates that it may be as much as 50 feet in places.

STRUCTURE

INTERLAYERING

The gneisses and schists of the Spruce Pine district are complexly interlayered and succeed one another apparently without systematic repetition. Mica gneiss and hornblende gneiss or schist are by far the most abundant types, and these are interbedded on both a large and a small scale. The individual layers range from a fraction of an inch to several hundred feet in thickness, but they rarely exceed 50 feet in thickness. The layers taper gradually, and in places rather abruptly, along their strike, so that various types interfinger with one another. Sequences only a few hundred yards apart along strike differ markedly. As a result of this interfingering and the scarcity of rock exposures, contacts can not be traced with any assurance; in fact, most boundaries are inferred. In addition, since most outcrops include more than one rock type in layers which are too thin to map separately, it is possible to map only the dominant type. It can be taken for granted that each rock type designated on the map includes smaller amounts of one or more of the other rocks.

Most of this complex interlayering and interfingering is probably an original structure formed by successive deposition of contrasting sedimentary, and perhaps volcanic layers of different areal extents. The uniformity of layering on a small scale seems to be a sedimentary feature and the interfingering resembles that generally noted in extensive terranes of unmetamorphosed sediments. If the hornblende gneiss and schist were derived from mafic intrusives, at least part of the interfingering may result from thin, tapering sills intruded into stratified rocks.

FOLIATION AND LINEATION

Foliation is well developed in all metamorphic rocks of the district. A large proportion of almost all rocks consists of mica flakes or needlelike hornblende crystals. These inequidimensional minerals are oriented in parallel planes so that schistose cleavage is marked. In almost all localities this cleavage is parallel to the layering of the different interbedded rocks. In a few localities where mica gneiss has a small proportion of mica, most of the flakes are at an appreciable angle to the banding of the rock.

Linear fabric resulting from parallel alignment of the long dimensions of hornblende needles in hornblendic rocks is not common. Though these needles generally are parallel to the layers, they seldom line up in one direction on these layers but point in diverse directions. In some localities, however, such lineation has been noted.

FOLDING

The older metamorphic rocks of the Spruce Pine district have been subjected to at least two periods of folding. The earlier deformation is recorded chiefly in the development of foliation and lineation. In addition, at a few places the layers can be seen to have been sharply folded isoclinically on a small scale. The difference in dip or strike of the opposite limbs of the folds is commonly not more than 5°. The beds are reversed in a strip along the fold axis only a few inches wide, and in this area it is uncertain whether the foliation is at a high angle to the bedding or whether it too is reversed. These tight folds probably were formed during the ancient deformation that resulted in regional dynamic metamorphism.

The foliated rocks have been tilted more or less steeply. The diverse attitudes in different parts of the district seem to indicate that this folding was later than the regional dynamic metamorphism. The tilting is presumably an effect of large-scale folding. The absence of key beds makes it impossible to trace out the large structures and to delineate definite anticlines and synclines; fold axes are recognizable in only a few places. Inasmuch as the large-scale general geologic map has been completed for only a part of the district, conclusions regarding such structures remain tentative and general.

The general strike is to the northeast and most dips are steep to the southeast, in conformity to the Appalachian regional structure. In the northeastern part of the district near Plumtree the rocks are relatively flat and are irregularly but gently warped. Across the northern and western sides of the district the dips are rather uniformly steep to the southeast. South and southwest of Newdale moderate to steep dips to the southwest and west are common though not general. The structure of the metamorphic rocks along the southeast side of the district, in the belt of large intrusives of fine-grained pegmatite, is highly irregular. Most dips are moderate to steep but may be in any direction and vary abruptly from place to place.

Locally in all parts of the district the foliated rocks have been bent into small upright or overturned anticlines and synclines with flank lengths of a few feet. In places the foliation has been closely crumpled into tiny crenulations that commonly have V-shaped crests and troughs. The axes of most of these small folds plunge gently or moderately to the south or southwest, but other attitudes are not rare. These small-scale folds are presumably drag folds associated with larger structures and so probably indicate the general attitude of the major features. Some may be related to faults.

The regional dip of the foliated rocks to the southeast seems to have controlled the distribution of pegmatites. The large bodies of fine-grained pegmatite are all near the southeast side of the district. The bodies of coarse-grained pegmatite are abundant in a curved belt extending from the north, along the northwest and west sides of the big intrusives. Almost none occur to the southeast. The fine-grained pegmatite presumably represents the parent magma from which the other pegmatites were derived or is itself a derivative of a hidden subjacent mass. The general scarcity of systematic joints and of discordant pegmatites in the district indicate that the role of fractures in conducting magma upward must have been minor. Cleavage planes were the easy passageways. Since on the whole the foliation dipped southeast, coarse pegmatites would necessarily be asymmetrically distributed with respect to the large bodies of fine-grained pegmatite because of the greater ease of passage of magma along rather than across the layers.

FAULTING

Many faults with diverse attitudes offset all the rocks of the district, except possibly aplite and basalt. The fault surfaces are slickensided and generally coated with manganese oxide. Similar striations on foliation planes and pegmatite contacts attest to other shearing movements. Lack of key beds makes it impossible to determine most displacements, but some are certainly only a few inches or a few feet and probably most of them are small. The spatial relations of large rock masses encountered during mapping have not been such as to necessitate the postulation of major faults to account for the structure. The chloritic amphibolite may be evidence of a large shear zone.

Many of the minor faults may be due to the emplacement of the larger pegmatites and others may have occurred during later regional uplifts.

JOINTING

Systematic tectonic joints are rare in the district. Locally they are well developed in hornblendic rocks, which seem to be more brittle than micaceous ones. Irregular fractures extending in all directions are common. Expansion joints parallel to the local land surface are numerous, particularly in the large bodies of more massive, fine-grained pegmatite.

DEFORMATION BY INTRUSIONS

The intrusion of dunite seems to have caused little deformation in the wall rocks. The contacts crosscut the older rocks in part, and elsewhere the walls seem to have been shoved apart as the magma rose between steeply dipping foliation planes.

The pegmatite magma penetrated upward and laterally mainly along the layers of the earlier foliated rocks. Most of the coarse-grained intrusives are conformable, and elongate parallel to the strike of the metamorphic rocks, though fine details of the contacts show all to be discordant. Thus their positions and forms seem to have been controlled mainly by pre-existent structure. Some of the smaller conformable pegmatitic lenses, particularly those in flat-lying gneiss in the northeast part of the district, have been completely mined away without revealing any trace of the channelway through which the magma entered. In these places the country rock must have been opened along the foliation planes by tectonic forces or magma pressure to allow the fluids to pass and then to have closed without trace of the movements.

The larger bodies of fine-grained pegmatite, however, did cut across the foliation on a large scale, and displaced and crumpled the older rocks. Many of the small faults seem to have been caused by the magma making room for itself. Hundreds of inclusions of various wall rocks were broken off and engulfed in the intrusives. These range in length from a few inches to half a mile and are common throughout the big pegmatites, though concentrated near their borders. They commonly parallel the walls from which they were derived but may be diversely oriented. Many are considerably crumpled, and most contain considerable pegmatitic material. Many masses of gneiss within pegmatites may have been roof pendants now isolated from the country rock by erosion. These perhaps are essentially in their original positions, but the rock formerly continuous with them along their sides was completely removed to higher or lower levels by the intrusions.

Aplite and basalt seem to have filled open fractures without disturbing their wall rocks.

ECONOMIC GEOLOGY OF THE DISTRICT

GENERAL STATEMENT

Most of the mineral products of the Spruce Pine district are derived from pegmatites. The recent investigations have been directed toward those rocks and have been focused especially on mica and, to a lesser degree, on feldspar deposits. Other mineral resources have received only incidental consideration.

Pegmatites in the district have yielded the following industrial minerals: beryl, columbium-tantalum minerals, feldspar, kaolin, mica, quartz, rare earth minerals, and uranium minerals. Other actual or potential mineral products of the district include amphibole asbestos, building stone and crushed rock, chromite, garnet, kyanite, mica schist, olivine, and vermiculite. The distribution of the main pegmatite mineral products in the district is indicated in Table 1.

The four principal mineral products, listed in the order of their usual importance, are feldspar, kaolin, ground mica, and sheet mica. These are estimated to account for more than 90 per cent of the district's total mineral production.

PEGMATITE MINERAL PRODUCTS

BERYL

Beryl is a comparatively rare constituent of Spruce Pine district pegmatites. Most occurrences are along the southeast side of the district, especially toward the southwest end. The most notable localities are probably at the Biggerstaff Branch and Poteat mines in Mitchell County, and especially at the Ray Mine in Yancey County. Beryl occurs as fairly well formed, pale-green, hexagonal prismatic crystals, ranging from a small fraction of an inch to about 3 inches in diameter. It seems to occur mainly in pegmatites of moderate size which contain considerable perthitic microcline and to occupy inner positions near the core. Production has been incidental to feldspar and mica mining, and the total is probably of negligible commercial importance. No regular production of beryllium ore appears to be possible.

Gem beryl was mined years ago at two localities in Mitchell County and at one in Yancey County, but the total production seems to have been small. Small emeralds were obtained at the Grindstaff Emerald mine on Crabtree Mountain, and considerable aquamarine was found at the Grassy Creek Emerald mine. Aquamarine and golden beryl have also been obtained at the Ray Mine. Further information is contained in a report by Kunz (1907).

COLUMBIUM-TANTALUM MINERALS

Columbite-tantalite and samarskite occur in small quantities principally at a few feldspar mines in the Spruce Pine and Crabtree Creek areas, but also at several localities in the Mine Fork area (as Randolph mine) north of Burnsville. The most notable deposit is doubtless the McKinney mine in upper Crabtree Creek valley. These minerals seem to occur in association with replacement units in large pegmatites rich in perthitic microcline. A few hundred pounds of both minerals have been produced as by-products of feldspar operations but resources appear to be inconsequential. Other known localities include the Deake, Pink, and Wiseman mines in Mitchell County and the Ray mine in Yancey County.

FELDSPAR

The value of feldspar produced in the Spruce Pine district has exceeded that of any other mineral product in almost every year since 1920. The first shipments were made in 1911, from the Deer Park mine. North Carolina has been the leading producer in the United States each year since 1917, and most of its production has come from the Spruce Pine district. The economic geology of the feldspar deposits has been considered in detail by Olson (1944, pp. 41-51) so only a summary emphasizing recent developments will be included here.

Most of the feldspar produced in the district is of two general types: (1) "potash spar" for pottery manufacture chiefly, and (2) "soda spar" for glassmaking. The former consists mainly of perthitic microcline with quite small amounts of plagioclase feldspar (mostly oligoclase) and quartz. Because of the admixture, "potash spar" has several percent of soda, but the potash-to-soda ratio is ordinarily 3 to 1 or higher. Because in making pottery the feldspar is mixed with clay, it is ground to 200-mesh or finer. Soda spar consists mainly of plagioclase (mostly oligiclose) with smaller amounts of perthitic microcline and a little quartz, so that the soda content slightly exceeds the potash. Granular soda spar is mixed with sand in glassmaking and so is ground to about 20-mesh size. The two types are thus not sharply distinct. Most shipments are made up by blending various batches and are strictly controlled to specified composition by chemical analyses of samples. A third type, "corduroy spar," is the intergrowth of plates and wedges of quartz in microcline, or less commonly in plagioclase, called graphic granite. The quartz usually amounts to about 25 per cent of the rock and the resulting ground spar is especially siliceous.

High-potash spar is produced mainly from thick coarse-grained pegmatites that are well zoned. Microcline is the dominant feldspar in very few of the pegmatites. Only large and well-zoned pegmatites contain concentrations of commercial value. These occur as coarse microcline-quartz cores or intermediate zones adjacent to massive quartz cores or discontinuous central quartz pods. These zones are mined selectively, and blocks of perthitic microcline larger than about 2 inches are sorted out, cobbed, and loaded by hand. The distribution of such deposits in the district is indicated in Table 1 as potash block spar. They occur mainly in a belt along the southeast side of the district, enclosed in the big bodies of fine-grained pegmatite. Resources of minable high-potash block spar are generally believed to be low, though it is probable that other good deposits exist but fail to crop out.

Soda spar is produced in two ways. Some soda block spar is mined selectively, cobbed and sorted by hand from pegmatites less clearly zoned and less coarse than those which yield potash spar. The blocky plagioclase is usually in an inner zone where it is mixed with small amounts of microcline and quartz. Though plagioclase forms nearly half of most pegmatites, it generally occurs in grains and masses too small for economical hand-sorting. Deposits with block plagioclase have been worked mainly in the central part of the district. (See Table 1.)

Most soda spar in the district is now produced by large-scale milling of fine-grained pegmatite ("alaskite"). The rock is quarried, crushed, and ground, and the component minerals separated mainly by froth flotation. The feldspar concentrate comprises plagioclase with less microcline, and the soda content is a little higher than the potash content. Byproducts include ground mica and quartz sand. Enormous quantities of rock suitable for such milling exist along the southeast side of the district, though sites favorable for quarrying and convenient to transportation are not numerous.

KAOLIN

The production of kaolin (white china clay) has in recent years been in either second or third place in value of the mineral products of the Spruce Pine district; mica for grinding has competed with kaolin for second place after feldspar. The Spruce Pine kaolin is residual clay formed by decomposition in place of feldspar-rich rock originally low in iron-bearing minerals. Surface waters containing carbonic and organic acids have percolated into all of the rocks to variable depths and have converted feldspar into clay. The large stocks or sills of fine-grained pegmatite ("alaskite"), where favorably located, have been partially changed to white clay in places to depths of about 100 feet. Other rock types, though altered similarly, have not yielded commercially valuable kaolin deposits; coarse pegmatite occurs in masses too small to be economically mined for clay, and all other types of rock have such a high proportion of mafic minerals that the clay is too iron-stained for ceramic use.

The primary factor controlling the location of kaolin deposits is thus the presence of large bodies of fine-grained pegmatite. Not all such bodies, however, have been converted to clay. Kaolin deposits are restricted to pegmatites that crop out in areas of a well-developed strath along the major drainage lines. This strath consists of wide, flat valley bottoms along the upper reaches of streams and of sediment-capped flat terraces or gently rolling country along the rivers and major tributaries farther downstream. During a previous period of erosion, while the strath was being formed, circulation of ground water in these areas kaolinized the underlying rocks. The low altitude of the deposits and the gentle land slopes above them have favored their preservation from recent erosion.

The kaolin deposits consist of clay (apparently kaolinite mainly) with undecomposed feldspar (both plagioclase and microcline), quartz, and muscovite. Under the local conditions, microcline is more resistant to weathering than plagioclase and so has a higher ratio to plagioclase in kaolinized rock than in fresh rock. Minor amounts of biotite and decomposed garnet are present in places. Recoverable clay usually amounts to 15 to 20 per cent of the deposit. It is separated by a complex procedure involving grinding, washing, screening, settling, and flotation. Scrap mica is an imjortant byproduct. The feldspar and quartz are wasted in existing plants. Reserves of recoverable washed kaolin in the district are estimated to be between 3 million and 7 million short tons.

Detailed reports on the kaolin deposits by Bayley (1925), Hunter (1940), and Parker (1946) are available.

MICA

Sheet mica.—The mining of sheet mica is the oldest mineral industry of the Spruce Pine district. Prehistoric mining was carried on, presumably by Indians, and modern mining has continued since 1868. The annual and total values of sheet-mica production have in recent years been exceeded by those of other products but the importance of the industry continues to be great because of the strategic character of better-quality sheet mica in war time. For this reason most of the recent work of the U. S. Geological Survey in the district has been focused on sheet-mica-bearing pegmatites. As a consequence, several detailed reports on these deposits are available or in preparation; these include reports by Sterrett (1923), Kesler and Olson (1942), Olson (1944), Cameron, Jahns, McNair, and Page (1949), Jahns and Lancaster (1950), and Jahns et al. The present description is of a summary character; for more comprehensive and detailed information the reports cited should be consulted.

The range of color, quality, and size of sheet mica produced is considerable, and the different kinds are not uniformly distributed over the district. The colors of thin plates range from pinkish brown through brown and greenish brown to dark and light green. The mica in any single pegmatite is either of one color throughout or of two colors, each of which is limited to a distinct structural unit. Certain colors dominate in each part of the district (see Table 1), though some mica of each color is found in practically all areas. In the Ingalls, Spruce Pine, and Crabtree Creek areas, where large fine-grained pegmatite bodies prevail, most mica is green, brownish green or greenish brown. In the areas just north, northwest, and southwest of this belt (i.e., Ledger-Kona-Micaville and South Toe River areas) brown mica predominates, though greenish brown is common. Still farther northwest and west (Hawk-Bandana-Shoal Creek and Black Mountain areas) reddish-brown mica is most abundant, but is accompanied by light-brown and a very little green mica. Green mica generally occurs in association with massive quartz cores or in perthitic microcline-rich pegmatites. Reddish-brown mica is commonest in perthitic microcline-poor pegmatites that have calcic oligoclase. In pegmatites having two colors of mica, green mica is usually near the core margins and brown in the wall zone.

Much mica is stained by specks, spots, and streaks of hematite and magnetite. These impurities may be arranged randomly or in lines crossing each other in regular patterns. Stained mica occurs throughout the district and is most common in areas where there are large bodies of fine-grained pegmatite.

Inclusions of small intergrown crystals, plates, and grains of many minerals are common between the sheets of mica books. Inclusions of quartz, plagioclase, garnet, muscovite, biotite, apatite, epidote, tourmaline, and kyanite have been noted. Inclusions seem to be common in all types of mica from all parts of the district but they are probably most abundant in green mica.

Structural defects that reduce the yield of trimmed mica include "A" structure, wedge-shaped books, "locky" cleavages, ruling, reeves, and bent and broken books. Green mica is especially apt to occur in wedge "A" books. These defects are so common throughout the district that perfect mica books are practically unknown.

Mica books yielding trimmed sheet must be at least 2 inches in diameter; most range from 5 to 8 inches. The size of mica books or the proportion of large books does not seem to vary geographically or with the type of deposit.

The fine-grained pegmatite of the large stocks (?) contains abundant flake mica but no books large enough to yield sheet. The smaller tabular or lenticular bodies of coarse-grained rock within fine-grained pegmatite and gneissic wall rocks may contain large mica books.

Books of a size, quality, and concentration to be of commercial importance are confined for the most part to pegmatites that consist dominantly of medium-grained plagioclase and quartz, or to zones of this composition within more complex pegmatites. Rock containing small to moderate amounts of perthitic microcline intermixed with plagioclase may be mica-rich also, but if perthitic microcline predominates most of the muscovite is green and has "A" structure. The mutual exclusion of important amounts of blocky perthitic microcline and of book muscovite in the same rock mass is the basis for the common division of commercially important coarse-grained pegmatites into mica deposits and feldspar deposits. Some pegmatites, however, yield both products, but ordinarily the value of one greatly exceeds that of the other and the two occur in different zones.

Though muscovite is irregularly distributed through practically all parts of every pegmatite, concentrations of commercial value are restricted. In the many pegmatites in which no zoning is apparent, mica is ordinarily disseminated throughout the body. The mica is not uniformly concentrated in all parts, but neither do the richer parts seem to be systematically distributed. Such deposits usually are in relatively thin lenses or sills in foliated rocks. The mica may be of any color except dark green, and it is generally flat and clear.

In pegmatites having only a thin border zone and a core, book mica is scattered through the core. A few pegmatites having two or more zones of subequal thickness likewise contain deposits of mica in the core.

In most zoned pegmatites book mica is concentrated in the wall zone. This distribution prevails in those having feldspathic cores, in those having massive quartz cores, and especially in the more distinctly zoned pegmatites having three or more units. Mica is about equally abundant throughout the thickness of the wall zones, but ordinarily the hanging-wall zone is substantially richer than the foot wall zone. The mica is generally flat, and is reddish brown, brown, or brownish green.

Mica concentrations along the margins of massive quartz cores or central quartz pods are of little importance in the district. They occur mainly in coarse pegmatites enclosed in large bodies of fine-grained pegmatite. The mica is invariably green, and "A" structure is moderate to extreme. Much of this mica is stained.

In a small proportion of pegmatites mica is especially abundant in shoots, which consist of fairly well defined, narrow, elongate parts of unzoned pegmatites or of particular zones. Such concentrations are commonest in the larger tabular and lenticular bodies. Shoots ordinarily plunge obliquely down the dip of the pegmatites at moderate to low angles, the most common directions being southerly. Some appear to be localized by outward rolls or sharp bends in the hanging wall, or by the crests in elongate lenticular pegmatites. Many doubtless reflect a thicker part of the pegmatite, and their elongate shape and plunging attitude probably indicate similar features for the whole body.

Available evidence indicates that the likelihood of any particular deposit being rich in mica does not depend on pegmatite shape, character of zoning, or type of mica distribution within the pegmatite. Correlation with mineralogy of the pegmatite has already been described.

In pegmatites that have been mined commercially, book mica generally constitutes about 2 to 6 per cent of the rock. Large volumes of pegmatite tend toward the lower figure. The recovery of salable sheet mica is commonly about 5 per cent of the mine-run book mica, the remainder, except for losses, going into scrap for grinding.

The geologic conditions in the district indicate that at least as much unmined mica exists as has been produced to date. The outlook for actual discovery of deposits not now exposed is, of course, not encouraging. It is hoped that completion of the geologic mapping of the district will make clearer the factors controlling the localization of productive pegmatites. Additional prospecting by exposing outcrops over wider surfaces and by core drilling should uncover further supplies. Future production can be maintained at a high level only at times of high prices or substantial subsidies.

Scrap mica.—Much scrap accumulates during rifting and trimming book mica to obtain sheet; in fact, well over 90 per cent of mine-run book mica necessarily becomes scrap. In mining for either sheet mica or feldspar, additional amounts of scrap mica are recovered from broken and bent books or books too small to trim, though much of this material goes to the dumps. In refining kaolin a large quantity of fine mica in the form of flakes and small books is recovered by froth flotation as a valuable byproduct. Similarly the production of feldspar by milling and flotation of fresh or little-altered fine-grained pegmatite has yielded very large amounts of scrap for grinding.

In recent years mining of scrap mica as a primary product has become commercially important. Weathered bodies of fine-grained pegmatite, similar to those worked for kaolin but also some less thorough kaolinized ones, are mined hydraulically or by power shovel and the mica is separated by washing and screening. These masses are commonly large and irregular, and may contain 10 to 20 per cent muscovite in flakes and small books. They occur mainly in the belt along the southeast side of the district. In most of these operations the kaolin and feldspar are not recovered, and the mica recovery in the fine sizes is very low.

Nonpegmatitic sources of material for ground mica include mica schist and byproduct mica from kyanite mining.

Resources of mica for grinding seem to be large, though the best deposits have been exploited. The rate of depletion of any one deposit is rapid. Because the easily mined and processed material is confined to the zone of weathering, the long-term outlook is less favorable than for mineral products obtained from unaltered rock.

QUARTZ

Quartz is a plentiful constituent in all Spruce Pine pegmatites, but only two types of occurrence are of economic importance. Many of the larger pegmatites have cores or large discontinuous central pods of massive gray, smoky, or white quartz. These bodies are most common in the perthitic microcline-rich pegmatites of the Spruce Pine and Crabtree Creek areas near the southeast border of the district. Perthitic microcline and green "A" mica are associated with the quartz, but they can ordinarily be cobbed out to yield quartz of high purity. Though large quantities of such material are available as a byproduct from feldspar mining, not much has been sold because of the great shipping distance to glassmaking centers. Uses demanding high purity, however, have accounted for small production. Thus, quartz from the Chestnut Flat mine in Mitchell County was used for the glass mirror of the 200-inch reflecting telescope for the Mount Palomar Observatory in California.

With the advent of froth-flotation production of feldspar, a fairly high-silica quartz byproduct has resulted from the separation of the disseminated quartz in fine-grained pegmatite. The rock being milled occurs near the southeast margin of the district near Spruce Pine and along the South Toe River near Kona. The quartz sand thus produced is used in plaster, concrete aggregate, and for road surfacing.

RARE EARTH MINERALS

Minerals containing metals of the rare earth group, mainly cerium, which occur in the Spruce Pine district include allanite and monazite, Allanite is a fairly common, though minor, constituent of pegmatites, especially along the north, northwest, and west sides of the district. It is associated with calcic oligoclase. Most of it is in small needlelike crystals, though blades as much as 6 inches long occur at the Tantrough mine a mile southeast of Burnsville. Because it is sparse and intergrown with feldspar, allanite is noncommercial even as a byproduct.

Monazite is extremely rare in the pegmatites, and no placer deposits are known.

URANIUM MINERALS

Uraninite, uranophane, gummite, autunite, cyrtolite, clarkeite, and torbernite, in addition to samarskite, occur in exceedingly small quantities in a few pegmatites. These are mainly rather large pegmatites, rich in perthitic microcline, mostly along the southeastern margin of the district. These minerals are so sparse as to yield small rare specimens only. Radioactivity in these pegmatites, except actually next to the minerals mentioned, is of such low intensity as to be barely detectable. Known localities include the Deake, Flat Rock, McKinney, Pink, and Wiseman mines in Mitchell County and the Carolina Mineral Company No. 20 and Ray mines in Yancey County.

OTHER MINERAL AND ROCK PRODUCTS

AMPHIBOLE ASBESTOS

Amphibole asbestos has been mined on a small scale from at least three deposits in the district. The principal production probably has been from the Frank dunite mass in Avery County, where small-scale mining has been carried on intermittently for years. Slip-fiber anthophyllite asbestos is reported by Hunter

(1941, pp. 43-45) to occur along the contact of the olivine rock with hornblende gneiss and along shear zones within the dunite.

Mining was undertaken about 1943 at the Blue Rock deposit in Yancey County on the northwest side of the South Toe River opposite the mouth of Blue Rock Branch. Two kinds of rock occur there, one consisting of matted groups of diverging coarse needlelike crystals from 0.5 inch to 6.0 inches long and the other of closely packed rosettes of radiating groups of fine fibers 0.5 to 1.0 inch long. The latter type has been mined selectively from a northeast-trending, nearly vertical zone about 20 feet wide in hornblende gneiss. Two irregular open cuts in line, one at about 40 feet higher than the other, have been worked; each is 15 to 25 feet wide, about 50 feet long, and as much as 20 feet deep.

Smaller production has also come from a similar deposit on a prominent rocky ridge about a mile northeast of Micaville.

Small amounts of asbestos are common in most dunite bodies and in many soapstone masses derived from hornblende gneiss.

BUILDING STONE AND CRUSHED ROCK

Various gneisses have been quarried on a small scale at numerous points in the district for local use as rough building stone or as crushed stone for road metal. Hornblende gneiss and small quantities of mica gneiss have been utilized in masonry for walls, houses, and larger buildings. These rocks are widely distributed throughout the district. The quarries are small and are worked sporadically as need arises. Many are enlargements of highway cuts.

Evenly layered mica gneiss with hornblende gneiss beds has been quarried beside the road a quarter of a mile north of Penland in Mitchell County. An unusually tough, massive, fine-grained mica gneiss was formerly quarried for crushed stone a quarter of a mile southeast of Normansville in Mitchell County. Evenly laminated hornblende gneiss is quarried intermittently a mile west-northwest of Rebels Creek beside the road to Kona. Ellipsoidal masses of hornblende schist from the chlorite-biotite schist on the northeast end of Tempa Mountain have been used in masonry of a business building in Spruce Pine. Waste rock from the dumps of various feldspar and mica mines, especially from the very large dumps of the McKinney mine on the east fork of Crabtree Creek, is much used to surface secondary and mine-access roads. This material consists mainly of feldspar and quartz fragments with fine-grained pegmatite and some gneissic wall rock. The value of much of it is lessened by considerable scrap mica, which gives poor traction for vehicles.

Soapstone was formerly obtained from many quite small openings scattered over the district. It seems to have been used nearby for house piers, chimneys and fireplaces and for grave markers. The deposits apparently are too small to sustain continuing production even if demand warranted it.

CHROMITE

Chromite occurs commonly as veins and irregular lenses in dunite in the Spruce Pine district, in sufficient quantities to excite interest in the commercial possibilities. The deposits have been investigated carefully by Hunter, Murdock, and MacCarthy (1942), who concluded that they are so small and of such low grade as to be workable only under abnormally high price conditions or as a byproduct of possible future production of olivine for manufacture of magnesium metal or salts.

GARNET

Garnet is a common mineral in several kinds of rocks in the district. Very few pegmatites lack garnet but in none is it more than a minor constituent. Mica gneiss is commonly garnetiferous and hornblende gneiss may be so, especially near large silicic intrusives and where associated with biotite-rich injection gneiss.

The only commercial production of garnet has been as a byproduct of kyanite mining from a deposit 2 miles southeast of Burnsville in Yancey County.

The most garnet-rich rock observed in the district is hornblende gneiss on the northeast slope of Fawn Mountain and along upper Blue Rock Branch in Yancey County. In places here garnet crystals as large as half an inch compose about half the rock. No production from this rock is known to have been attempted.

A zone of massive garnet rock occurs on a ridge crest 1.2 miles S. 84° E. of the highway bridge across the South Toe River in Newdale, Yancey County, on property of Thad Young. The zone, in altered hornblende gneiss, is perhaps 8 to 10 feet thick and trends west-northwest. Massive brownish-red garnet (almandite) composes most of the rock; small separate crystals and fine granules are less common. Fine granular epidote and matted fine actinolite needles as long as half an inch occur in small irregular masses. White quartz forms irregular veins and masses several inches across. A small prospect pit has been opened but no mining has been undertaken.

KYANITE

Kyanite is a common accessory mineral in mica gneiss and schist at many places in the Spruce Pine district and is especially abundant near Bandana in Mitchell County and in much of the Black Mountains area in Yancey County. It also occurs less commonly in pegmatite and in quartz veins near Bandana. At least one shaft more than 30 feet deep was sunk about 1926 by E. B. Ward near Bandana in pegmatite or vein rock containing coarse kyanite blades, but little seems to have been produced. Further details are reported by Stuckey, (1932, pp. 665-669).

The only commercial development of kyanite in the district was undertaken 2 miles southeast of Burnsville, outside of the area mapped to date. Celo Mines, Inc. (later Mas-Celo Mines and Yancey Kyanite Co.) operated a large quarry, underground mine, and mill from late 1934 until early 1944. Dark-gray mica gneiss containing 10 to 15 per cent disseminated kyanite needles and blades up to 4 inches long was worked. The rock is reported by Mattson (1936, pp. 313-314) to have contained kyanite, quartz, biotite, muscovite, garnet, albitic feldspar, apatite, beryl, pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, bornite, and chalcocite. In addition to the low-iron kyanite concentrate, byproduct abrasive garnet and thermally luminescent quartz were turned out. The value of scrap mica recovered was reduced by the predominance of biotite over muscovite. Details of the operation are reported by Mattson (1936, pp. 313-314) and by Trauffer (1936, pp. 46-48). A detailed investigation of the deposit was made in 1943 by N. E. Chute of the U. S. Geological Survey for the Reconstruction Finance Corporation; the results have not been published.

MICA SCHIST

Two types of mica schist have been mined for grinding. Muscovite schist has been mined from numerous small pits over a considerable area on Tempa Mountain a mile east of Spruce Pine. It consists of fairly coarse flakes of muscovite with minor biotite, quartz, and feldspar. The schist has been injected by many quartz veins ranging from thin stringers to masses as much as 7 feet thick. Near these veins the schist has been coarsened by recrystallization and the veins contain groups of flakes and small books of muscovite. Much of the mica produced has come from the veins. This material was dry-ground for many years by the Victor Mica Co.

Chlorite-biotite schist has been mined on the northeast end of Tempa Mountain and on Hanging Rock Knob. The open cuts extend along the hillsides a little more than 100 feet and have a maximum depth of about 30 feet. Since the dip is into the hill, the depth of overburden is becoming great and underground mining will have to be undertaken. The rock has been dry-ground without beneficiation to give an impure ground mica containing actinolite, which has been in demand for rolled asphalt roofing.

OLIVINE

Olivine of refractory grade occurs in five dunite masses in the Spruce Pine district. It has been produced intermittently on a small scale by the United Feldspar and Minerals Corp. since about 1935 from the Daybook deposit 4 miles north of Burnsville in Yancey County. The fine-grained olivine has been extensively altered to serpentine and in addition contains deleterious bronzite and talc, so that careful hand cobbing and sorting is necessary to maintain refractory grade. The iron content of the olivine is said[1] to be undesirably high. More than 3,000,000 tons of relatively unaltered olivine has been estimated by Hunter (1941, p. 52) to exist in the Daybook deposit. The other deposits have been worked little or not at all but could supply much additional material.

[1]McDowell, J. S., Harbison-Walker Refractories Co., Pittsburgh, Pa., oral communication.

VERMICULITE

Vermiculite occurs in the dunite bodies in the Spruce Pine district, and is especially common in the Frank deposit in Avery County and in the Daybook deposit in Yancey County. Murdock and Hunter (1946, pp. 17 and 39) report that in the Frank deposit it is associated with anthophyllite asbestos along interior faults and with talc in a marginal zone; similar interior and marginal vermiculite zones exist in the Daybook deposit. The vermiculite appears to have been formed by alteration of chlorite, which in turn is a secondary mineral derived from the original dunite. A little vermiculite has been produced from the Frank area.

Vermiculite of quite different association occurs in many pegmatites as a result of alteration of primary biotite. This vermiculite, or biotite, usually forms either subhedral books or narrow strips as much as 5 feet long. A deposit of possible commercial value is reported by Murdock and Hunter (1946, p. 37) at the head of Little Bear Creek in Mitchell County.

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